Optimizing Search Strategies Through Application of Operations Research and GISystems

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Mountaineer Area Rescue Group

What is Search and Rescue?

- Search: To locate persons in distress
- Rescue: To retrieve persons in distress, provide for their initial medical or other needs, and deliver them to a place of safety

- SAR is an inherently spatial problem
- “Search” typically accounts for disproportionally large percent of the effort

SAR is Unique to Emergency Response

- SAR is abstract (at least the Search part)
  - In most types of emergency response we can see the problem directly.
    - Car crash, burning building, injured pedestrian, etc
  - In SAR we are looking for something that we can not see (where is the subject?)

Where Do We Start Looking?

- "Search" for a missing subject could be considered the proverbial "needle in a haystack"
  - Search is an emergency and time is of the essence
    - Subject may be injured / will not survive indefinitely
    - Clues deteriorate over time
    - Weather
    - Availability of resources

- Goal of search management is to maximize the probability of success (finding the missing subject) at the greatest rate possible.

PSR
(Probability of Success Rate)

Improving the Success Rate

- Majority of searches are resolved within a few hours
  - Only about 1% – 3% required Extended Planning of operations
- Extended searches typically encompass relatively large geographical areas
- Two options for improving the Success Rate
  - Reduce the search area
    - Search in most likely areas first
  - Increase the rate of detection
    - Proper resource allocation

Application of Operational Research to SAR

- Need a systematic method to prioritize regions within the search area and evaluate progress.
  - SAR operations typically time and resource limited
- OR provides framework to aid in decision-making and improve efficiency.
  - Developed during WWII to search for enemy submarines and improve resource allocation[1]
  - Bayesian Probability Theory
    - Assigning a probability to a hypothesis and adjusting the probability through testing without needing to fully resolving the hypothesis

$$P(\alpha_i|\beta) = \frac{P(\alpha_i) \times P(\beta|\alpha_i)}{\sum_{j=1}^{k}[P(\alpha_j) \times P(\beta|\alpha_j)]}$$

$a_1, a_2, \ldots, a_k$ are mutually exclusive events (hypothesis), of which none has a zero probability. b is any event (data used to test the hypothesis).

1. Koopman, B.O., "Search and Screening: General Principles with Historical Applications", Pergamon Press, New York, 1980., 2003.

Bayesian Probability as Applied to SAR

- Bayes Theorem in SAR Form
  - Adjusted POA (*a posteriori*) to predict the likelihood a subject is still in an area that had been searched (failure to detect)[1].

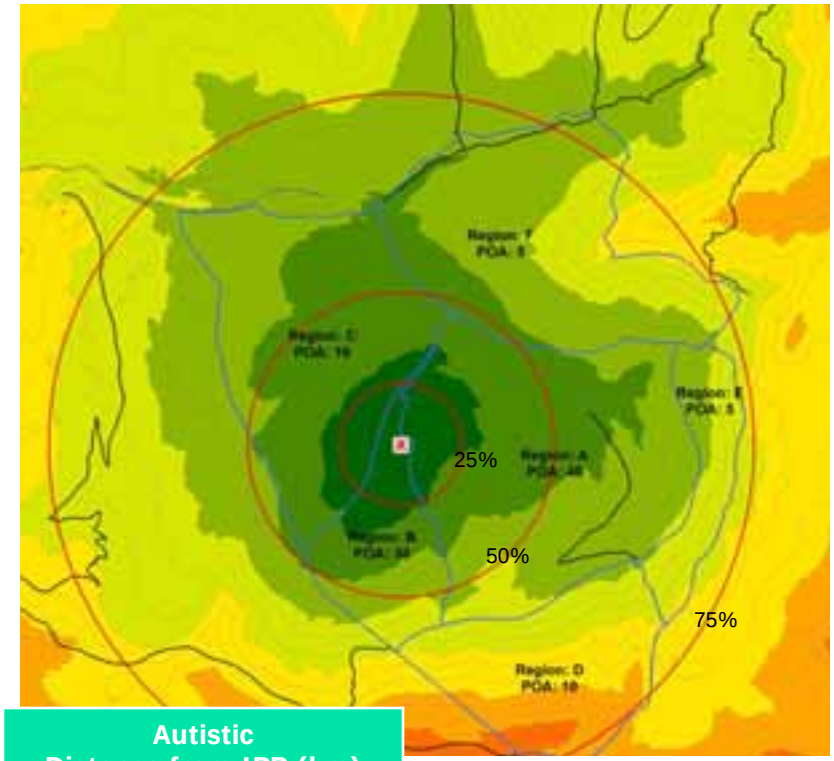
$$POA_{i-new} = \frac{POA_{i-a\,priori} \times (1 - POD_i)}{\sum_{j=1}^{k}\left[POA_j \times \left(1 - POD_j\right)\right]}$$

$POA_{i\text{-}a\ priori}$ – a priori Probability of the subject being in Segment i.
POD_i - Probability the subject would have been detected had the subject been in Segment i.
$(1\text{-}POD_i)$ – Likelihood the subject would not have been detected had they been in Segment i.
$S(POA_j \times (1\text{-}POD_j))$ – Overall probability that the subject is somewhere within the search area and subject can be detected with the available resources.

1. Cooper, D.C, Frost, J.R., Robe, R.Q., "Compatibility of Land SAR Procedures with Search Theory", NSARC, 2003.

Defining the Search Area

- Search area is defined by a collection of methodologies
  - **Theoretical**
    - Distance traveled
    - Historical/Categorical mobility data
  - **Statistical**
    - Historical/categorical search data
  - **Subjective-Deductive**
    - Subject and environment specific

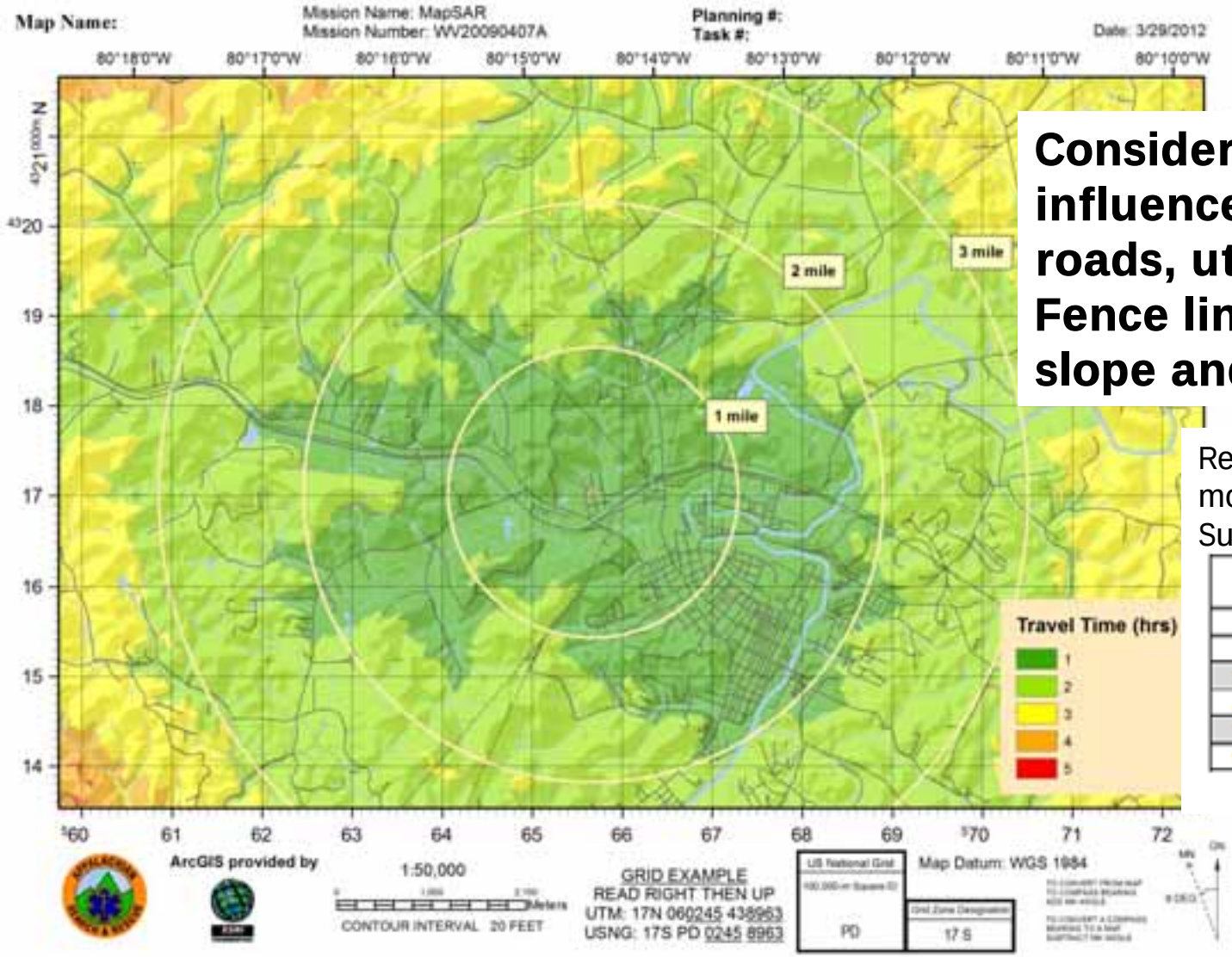


Autistic Distance from IPP (km)	
n	20
25%	0.6
50%	1.6
75%	3.7
95%	15.2

Theoretical and Statistical Search Area

ISRID Data

Theoretical Search Area…Improved Model



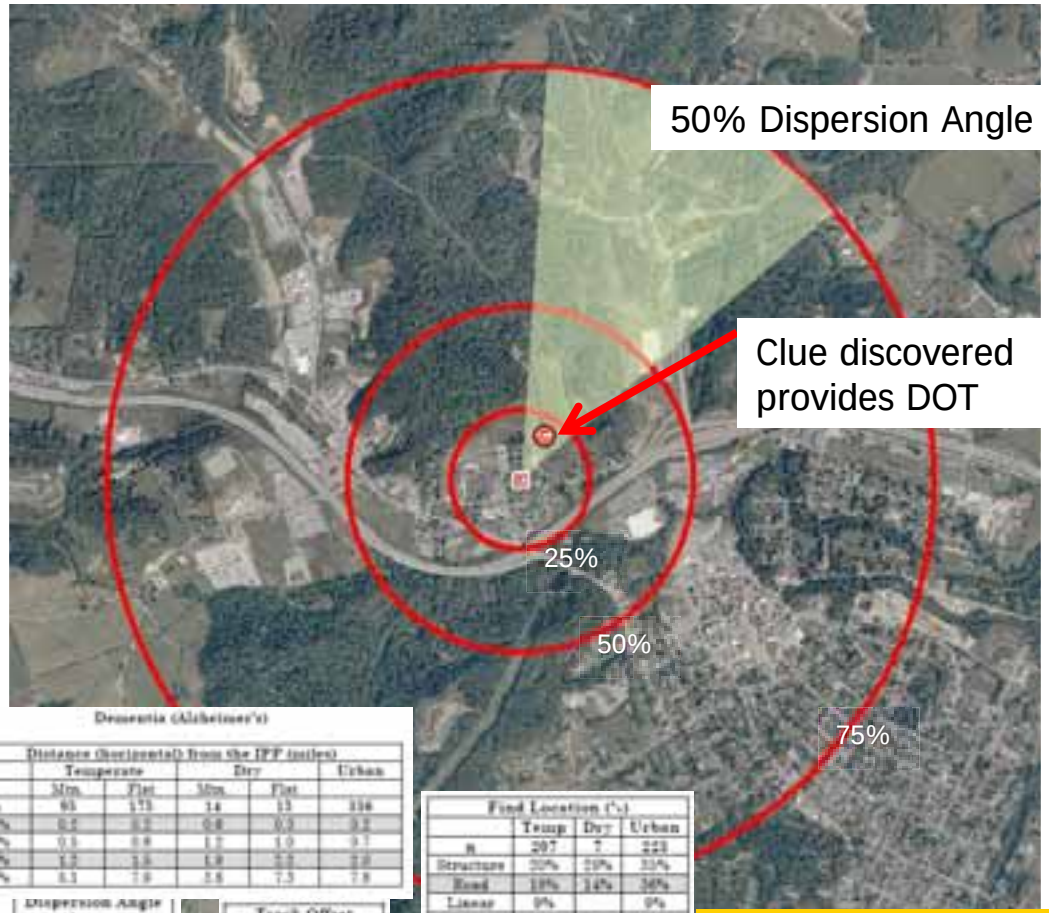
Considers the influence of trails, roads, utility ROWs, Fence lines, water, slope and vegetation

Recorded periods of mobility for Dementia Subjects

	Mobility (hours)	
	Temperate	Dry
n	42	6
25%	0	
50%	0.25	4.5
75%	3.8	
95%	18	

Statistical Search Area

- Information reflecting the distances other subjects traveled given similar conditions
  - Generalized subject behavioral profile
  - Data is available from a number of sources.
  - Improved models if data is specific to your area[1]



Dementia (Alzheimer's)

Distance (horizontal) from the IPP (miles)	Temperate		Dry		Urban
	Mtn.	Flat	Mtn.	Flat	
n	95	175	14	13	116
25%	0.5	0.5	0.8	0.5	0.2
50%	0.1	0.4	1.7	1.0	1.1
75%	1.2	1.5	1.9	2.5	2.0
95%	6.1	7.0	5.6	7.3	7.8

Dispersion Angle (degrees)	Temperate	Dry
N	11	
25%	11	
50%	62	
75%	66	
95%	70	

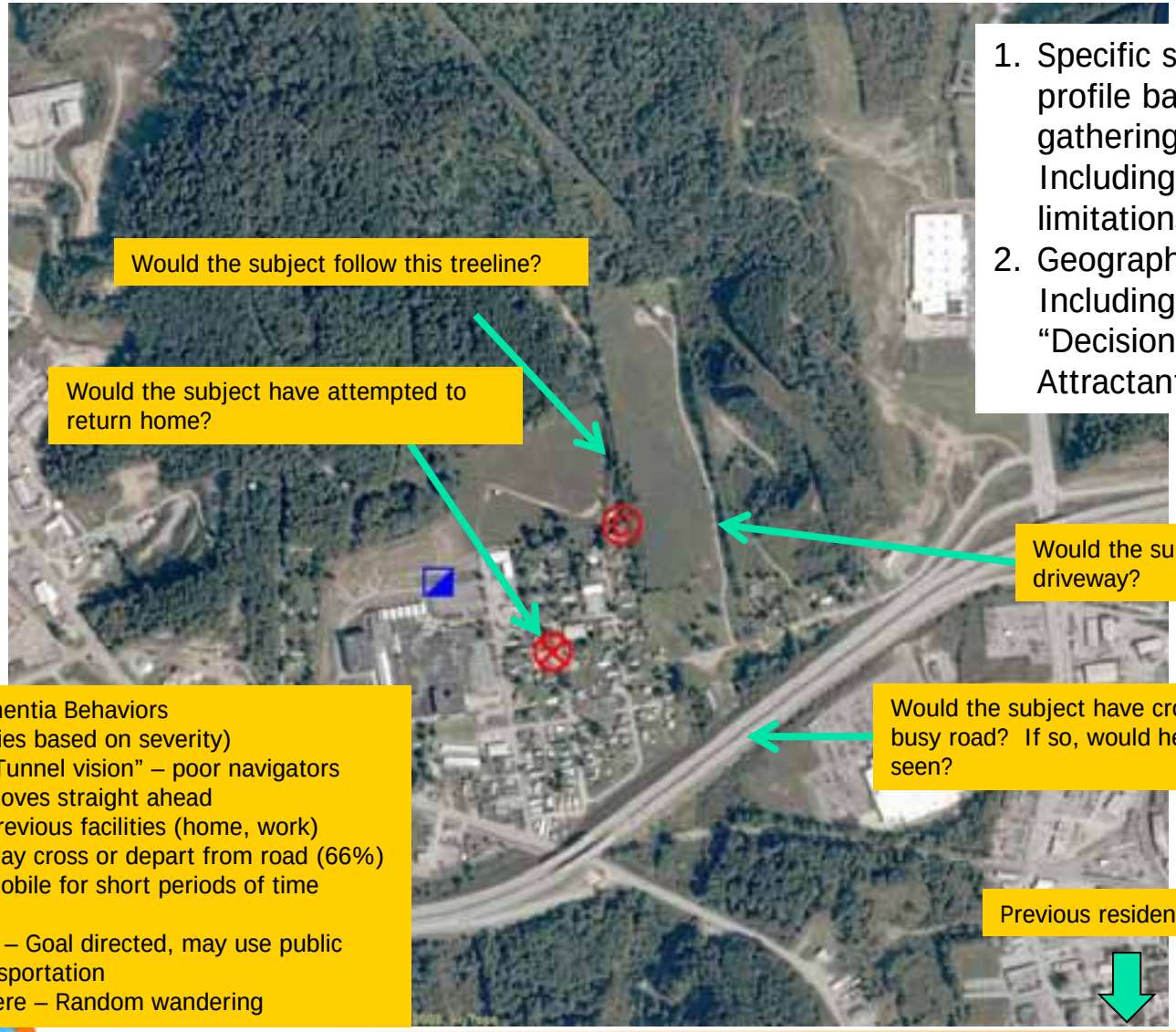
Track Offset (meters)	
N	110
25%	4
50%	15
75%	71
Max Zone	307

Find Location (%)	Temp	Dry	Urban
n	207	7	443
Structure	50%	29%	35%
Road	18%	14%	36%
Linear	9%		9%
Drainage	9%	14%	4%
Water	7%	14%	6%
Brush	6%		1%
Scrub			
Woods	11%		3%
Field	14%	29%	6%
Rock			

1. Doherty, P., Guo, Q., Liu, Y., Wieczorek, J., and Doke, J., "Georeferencing Incidents from Locality Descriptions and its Applications: a Case Study from Yosemite National Park Seach and Rescue", Transactions in GIS, 15(6): 775-793, 2011..

Koester, R.J., "Lost Person Behavior: A search and rescue guide on where to look - for land, air and water", dbS Productions LLC, 2008.

Subjective – Deductive Reasoning



1. Specific subject behavioral profile based on information gathering / interviewing. Including mental and physical limitations.
2. Geographical profile of the area. Including the identification of "Decision points" and Attractants.

Dementia Behaviors
(varies based on severity)
1. "Tunnel vision" – poor navigators
2. Moves straight ahead
3. Previous facilities (home, work)
4. May cross or depart from road (66%)
5. Mobile for short periods of time

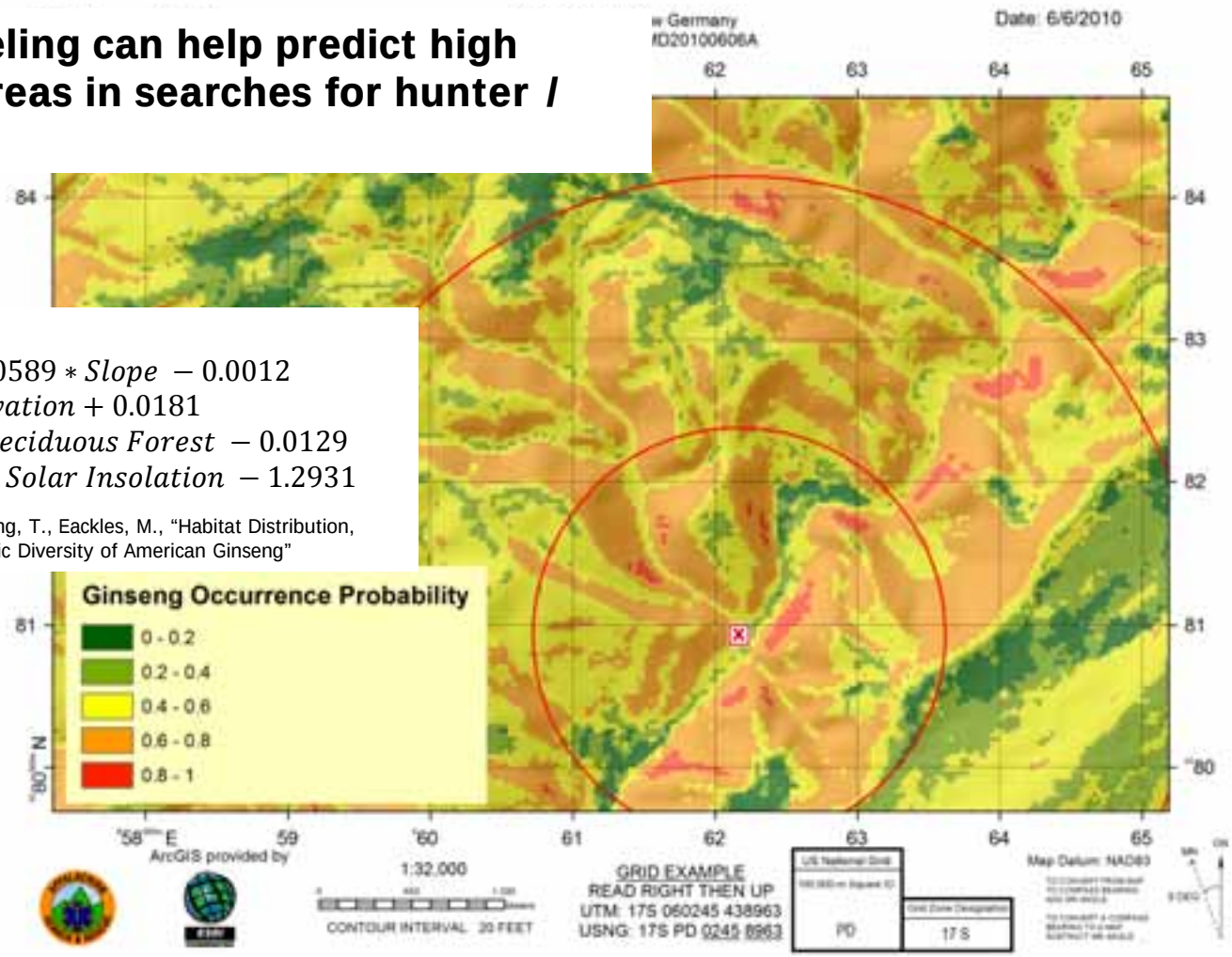
Mild – Goal directed, may use public transportation
Severe – Random wandering

Application of GIS for Search Area Minimization

Habitat modeling can help predict high probability areas in searches for hunter / gatherers.

$$
\begin{aligned}
Ginseng\ Habitat \\
&= \ 0.0589 * Slope \ - 0.0012 \\
&* Elevation + 0.0181 \\
&* \%\ Deciduous\ Forest \ - 0.0129 \\
&* Avg\ Solar\ Insolation \ - 1.2931
\end{aligned}
$$

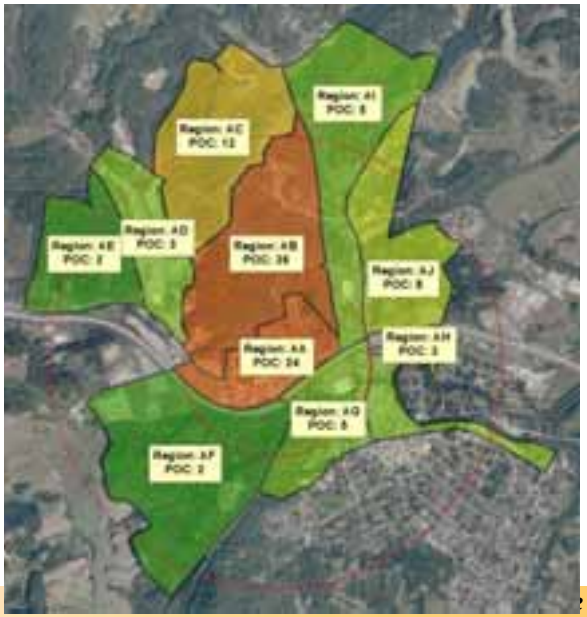
Young, J., van Manen, F., King, T., Eackles, M., "Habitat Distribution, Population Status and Genetic Diversity of American Ginseng"



Probability Regions

- A Region is a defined subset of the Search Area within which there is a uniform distribution of the likelihood of containing the search object[1] – Probability of Containment (POC)
  - Probability Density (Pden) – Probability/Area
  - Regions and region boundaries are based only on factors that affect decisions made by the missing subject
    - How the area is to be searched should not impact Regional boundaries.

Allows us to make the search area as small as possible while still maintaining a high probability of containing the subject



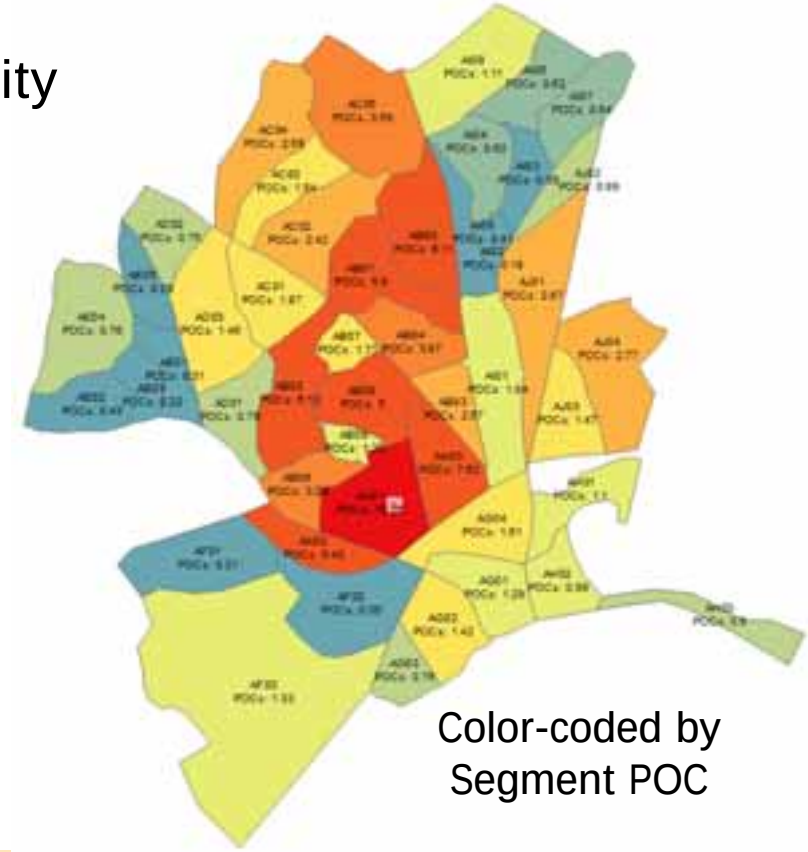
1. Land SAR Addendum to NSS V1.0, Nov 2011

Develop Searchable Segments

- Sub-divisions of Probability Regions based on logistical and operational issues associated with conducting the search itself
  - Resource capabilities / availability
  - Well defined field recognizable boundaries
- Segment POC
  - Area-weighted POC associated with the Region POC.

$$POC_{s,r} = POC_r \times \frac{Area_{s,r}}{Area_r}$$

$$POC_r = \sum_{s=1}^{Segments} POC_{s,r}$$



Color-coded by Segment POC

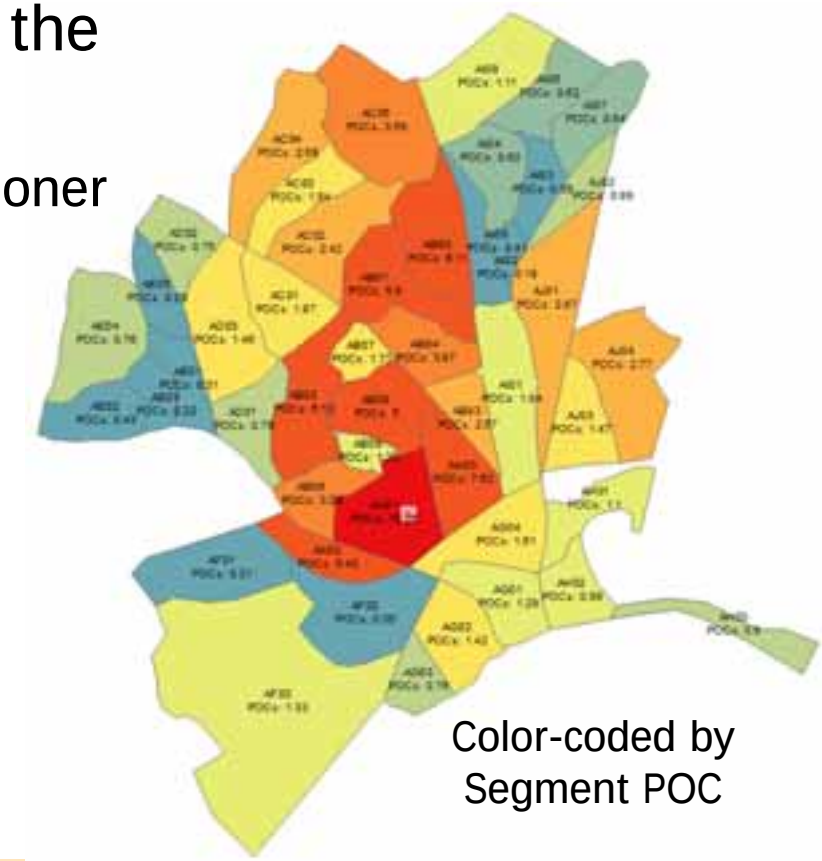
Tracking Success

- Segments are assigned based on POC with most likely locations being searched first.
- Goal is to reduce (minimize) the POC of a segment to zero
  - Hopefully locate the subject sooner
- Update POC after search of each segment

$$POC_{s,r,t1} = POC_{s,r,t0} \times (1 - POD_{s,r,t1})$$

$$POC_{s,r,t2} = POC_{s,r,t1} \times (1 - POD_{s,r,t2})$$

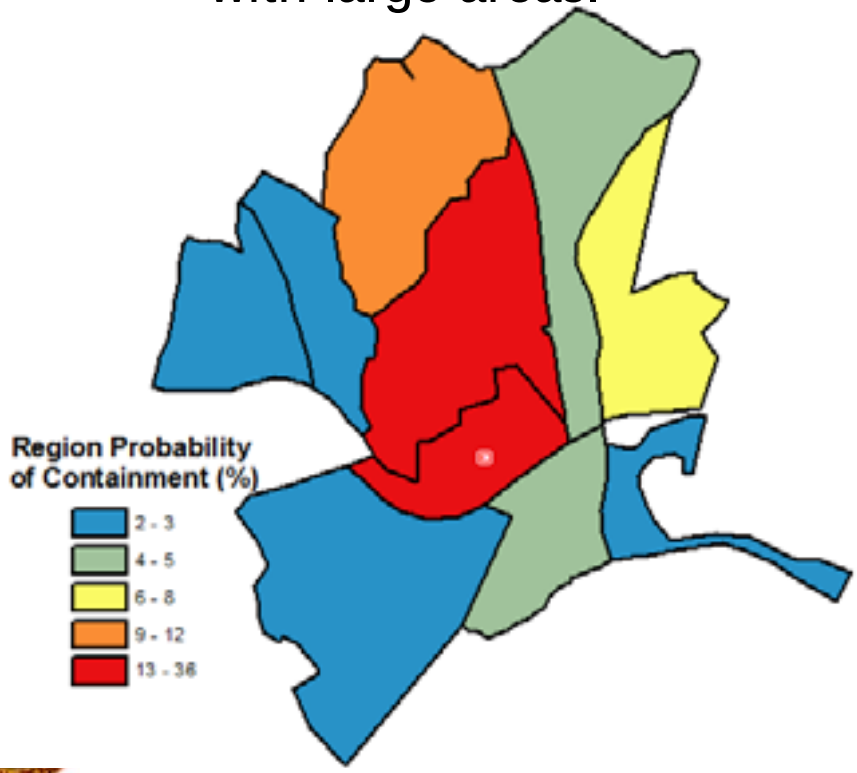
$$POC_r = \sum_{s=1}^{Seg} POC_{s,r}$$

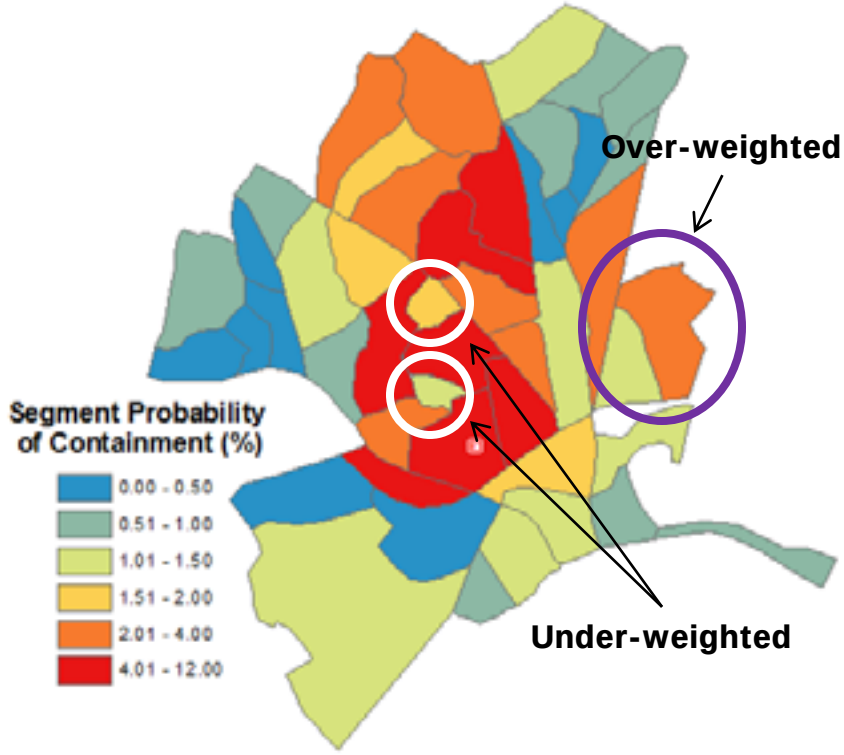


Color-coded by Segment POC

Overweighting Large Areas

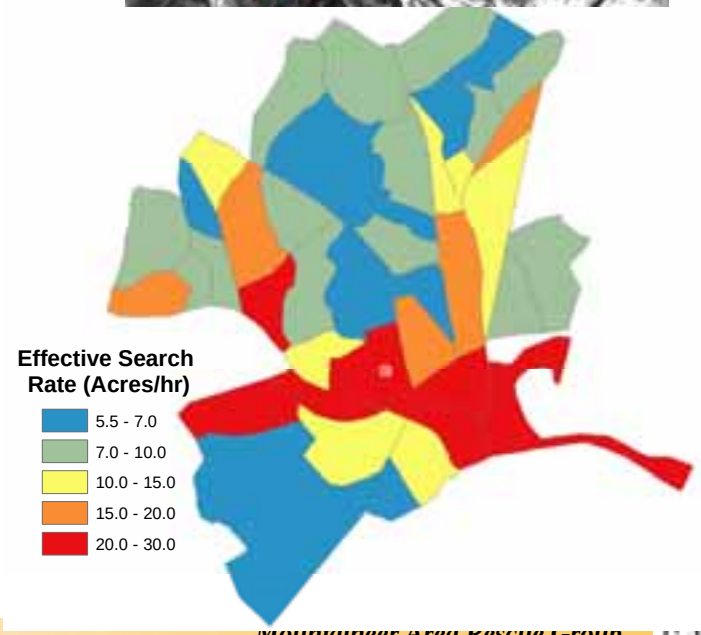
- Goal is to obtain minimize the POC over the entire search area as quickly as possible
  - Search Segment with highest POC
  - Area-weighted POC gives too much credit to segments with large areas.





Effective Search Speed

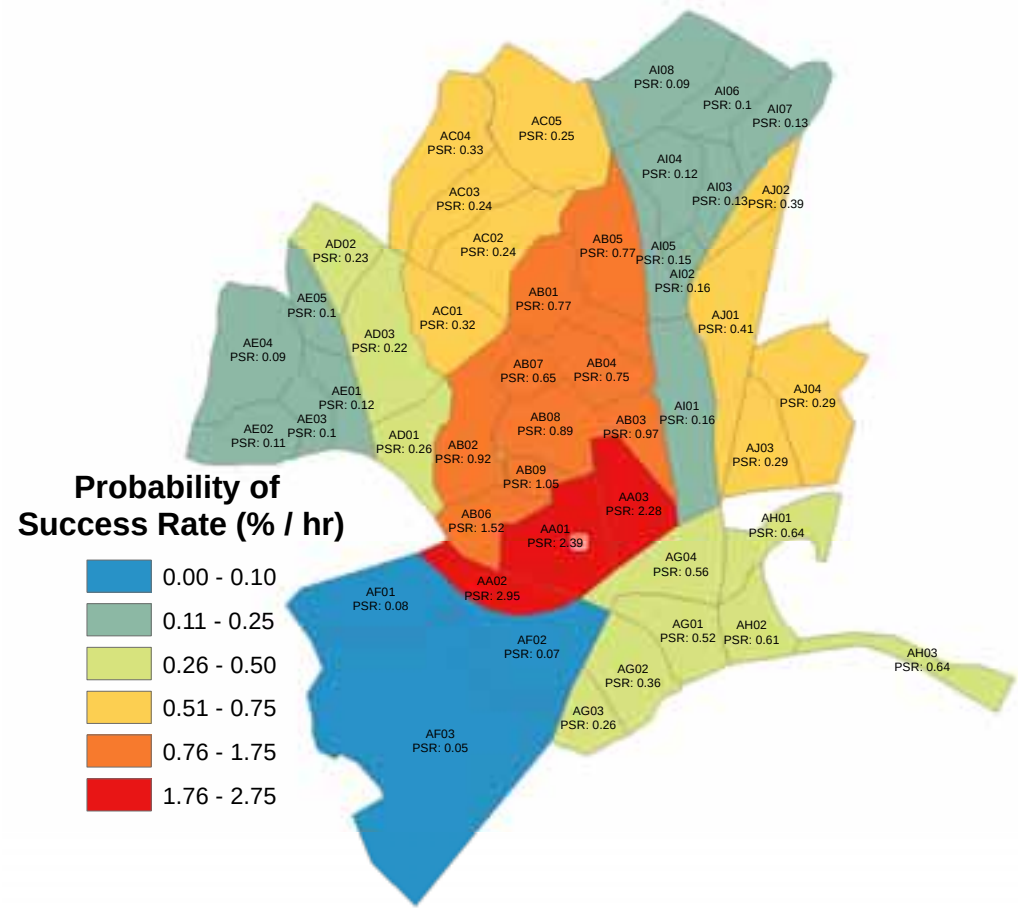
- If the goal is to minimize POC across the search area then we want to search the areas that would give us maximum probability in the least amount of time.
- Cost-Distance model to determine “Effective” search rate for each segment
  - Similar to theoretical search area algorithm
  - Accounts for vegetation, slope, travel aides, etc



Probability of Success Rate (PSR)

$$PSR_{s,r} = \frac{POC_{s,r} \times POD}{Area_{s,r}} \times Eff\ Search\ Rate$$

- Search areas that will achieve maximum POC as quickly as possible.
- Assumes a uniform POD across search area
- Additional optimization by considering POD
  - Resource type
  - Desired POD
  - Theoretically only need to reduce POC to next lowest level.



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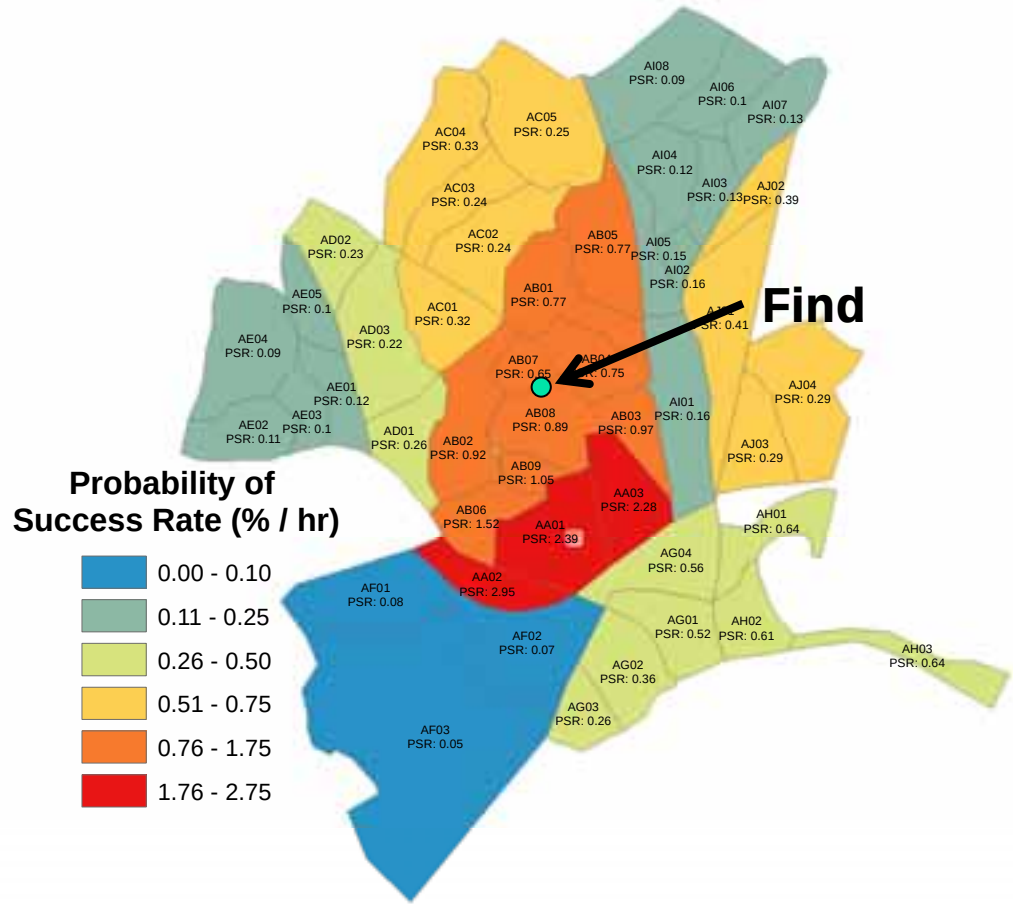

Conclusions

- Utilization of OR through Bayesian Probability provides a progress metric and helps maintain focus toward mission objectives
- Combination of Theoretical, Statistical and Subjective methodologies helps to reduce the overall size of the search area
- Optimize resource allocation through the use of Probability of Success Rate
- Further optimization achieve through resource selection and targeted POD.

Questions?

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